A Study on Event Screening for Downward Gamma-Rays with the GLAST Prototype Balloon Data

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ABSTRACT

The triggering and data analysis for the GLAST balloon prototype (Thompson et al. 2002), like that of the GLAST gamma-ray telescope (LAT) planned for launch in 2006, is much more flexible than was the case for the CGRO/EGRET instrument. Furthermore, the large data volume expected from GLAST/LAT precludes the type of manual event review that was done for EGRET data. Thus a great deal of attention must be given to the software "cuts" that are used to eliminate the huge background of events produced by charged cosmic rays, without reducing unnecessarily the efficiency for gamma-ray detection.

We have examined event by event the data from the August 2001 balloon flight and designed some candidate filters to cut events which were clearly charged particle background, and also others that are suspected of being non-downward-gamma-ray events. The cuts are based in part on experience with data from the SAS-2 and EGRET, but are modified to take into account the structural differences between GLAST/LAT balloon prototype and those earlier instruments. After application of these filters, designed specially for the balloon prototype, the remaining events are at least roughly compatible with the expected flux of atmospheric gamma rays. We describe the cuts being studied, as well as their effects on both the background and the gamma-ray efficiency. To check the performance of the filters and estimate the amount of remaining background, the filters are applied to events from detailed Monte-Carlo simulations of the prototype. We have simulated celestial gamma rays and an appropriate mix of proton and electron background including primaries, secondaries, albedo from the Earth, etc. (Mizuno et al. 2002).

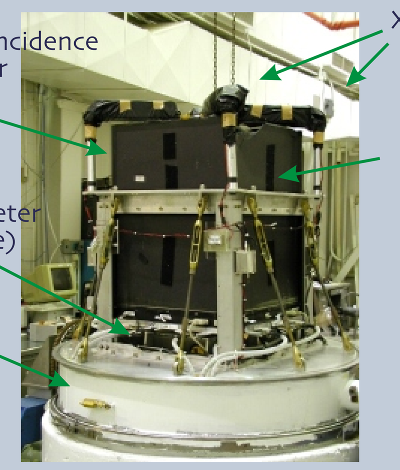
The filters presented here for the prototype, a partially-instrumented single tower, are substantially different from those that have been used for the full GLAST/LAT. The preliminary results for the prototype suggest some additional approaches to filtering that may be applicable to the flight instrument.

GLAST BALLOON PROTOTYPE

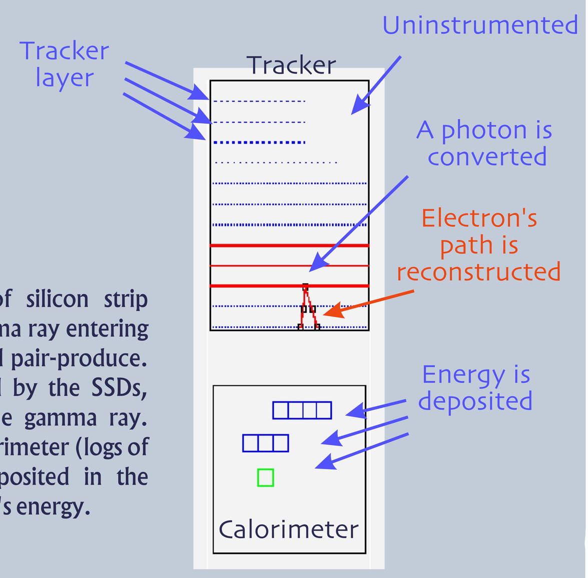
The balloon-borne prototype (Thompson et al. 2002) was similar to one of the 16 towers that will constitute the Large Area Telescope (LAT) on GLAST.

Objectives:
- Validate the LAT design in a realistic charged-particle background
- Develop an efficient data analysis chain

Launched August 4, 2001 - Primary dataset used is 10^5 events obtained during level float at ~ 4.5 g/cm^2



Overview.
The tracker is covered with the ACD tiles. The calorimeter and electronics are inside the gondola structure. The four plastic scintillaors (XGT) are mounted on the top.



Gamma-ray detection.
The tracker consists of the layers of silicon strip detectors (SSDs) and Pb foils. A gamma ray entering from above will hit one of the foils, and pair-produce. The resulting e^+e^- pair will be tracked by the SSDs, providing the incident direction of the gamma ray. The e^+e^- pair will continue into the calorimeter (logs of CsI(Tl)); the sum of the energy deposited in the calorimeter logs will give the gamma ray's energy.

Because of limited funding, resources, and schedule time for this balloon prototype, some portions of the tracker volume were not instrumented with SSDs. In the above figurw, the uninstrumented volume is blank. This uninstrumented volume causes the event analysis to be somewhat distorted, as partially described below.

Comparison of the Balloon Prototype and one of the 16 LAT Towers

	Balloon Prototype	LAT Tower
Tracker Face Area	32 cm × 32 cm	39 cm × 39 cm
Tracker Layers	2 dimension × 13 lyr	2 dimension × 18 lyr
Si Strip Ladder	Partially instrumented	Fully instrumented
Gap betw. ACD and CAL	9 cm	0 cm

PHILOSOPHY USED IN THIS WORK

Because of the large ratio of background events to celestial gamma rays, we attempt to cut an event if there is any chance it was not produced by a useful downward-moving gamma ray. A useful gamma ray is one for which the recorded event contains enough information to provide reasonable direction and energy. Thus some real gamma ray events are cut, which contain little or no astrophysical information. In most cases these are lower-energy gammas (< 100 MeV) which pair-produce in the lower part of the Tracker. In these cases, the information from the Tracker is minimal, and such events can be indistinguishable from background events such as albedo.

We examined the float data event by event and designed filters to remove suspicious ones, while keeping as many good events as possible. Examples of bad events cut by each filter are shown in the right figure in each panel bellow. The performance of the filters was tested by applying to simulation events. Nominal gamma rays and a cosmic-ray model were simulated (Mizuno et al. 2002). The performance of each filter is shown in the left figure in each panel bellow (See Z-direction-filter panel for caption.)

The filter set described in this paper is tailored to limitations of the Balloon Prototype. The application of the full-LAT filter set, which was developed based on simulations and utilizes all detector information, to the balloon data was restricted by the difference of the instrument designs and the progress of calibration and software development. This filter set for the prototype suggest some additional approaches that may be applicable to the flight instrument.

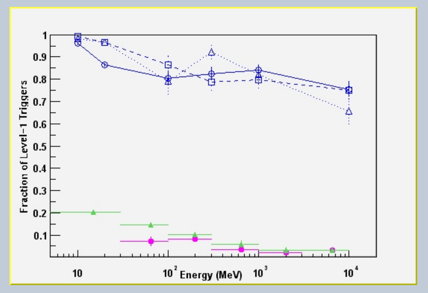
FILTER: ANTI-COINCIDENCE DETECTOR (ACD)

If (any ACD tiles are lit) then cut

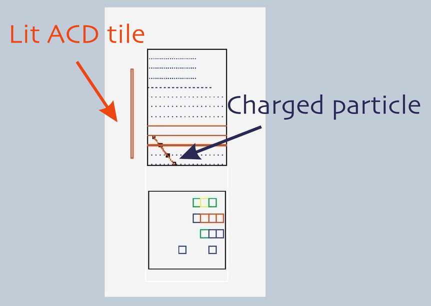
This is a simple detector veto for charged particles.

The charged particles not cut are almost entirely upward-moving ("splash") albedo events which sneak in between the bottom of the ACD array and the side of the calorimeter; these are the target of several of the filters applied later. Because of a larger gap between the ACD and calorimeter than will be present in the spaceflight GLAST/LAT, the balloon prototype is especially susceptible to these splash albedo events.

At 300 MeV, more than 80% of the simulation photons are accepted. Most of those lost are pair-converted in an ACD tile or in the pressure vessel or thermal insulation around the instrument, and are thus not useful. Since self-vetoing photons are rare, the more sophisticated selection for the LAT using full ACD information and visible energy was not applied.



Fraction of simulation events passing through this filter. See Caption in the Z-Direction Filter.

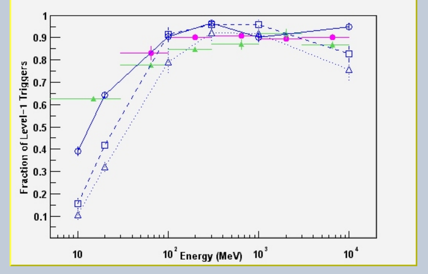


A flight event cut by this filter - A charged particle entering from the left hits an ACD tile.

FILTER: Z-DIRECTION

If (γ is not downward) then cut

This filter cuts events if the reconstructed direction of the incident particle is not downward . If the reconstruction somehow fails, the direction vector of the incident particle is left null, and such events are cut by this filter, too. Actually, the majority of the events cut by this filter are such reconstruction-failed events. With improved reconstruction algorithm, the reconstruction-failed events are expected to be reduced.



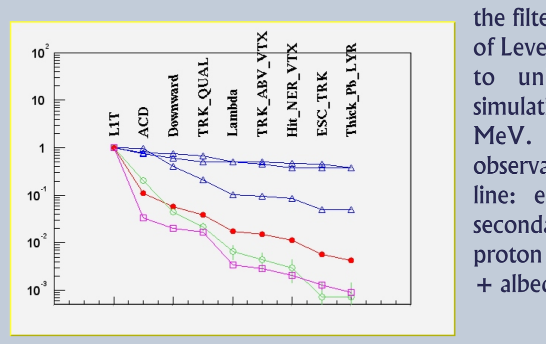
Fraction of simulation events passing through this filter.
Gamma rays:
- blue solid line and circles, zenith angle = 0°
- blue dashed line with squares, 30°
- blue dotted line with triangles, 45°

Electrons (primary, secondary, and albedo) green
Protons (primary, secondary, and albedo) magenta

CUMULATIVE FILTERING

After the flight and simulation data are screened with all the filters, the number of electrons and protons is reduced by three orders of magnitude, while most of the gamma-rays (300 MeV, 30°) are saved. Considering that the prototype has a large gap between the calorimeter and the shorter ACD array, this background rejection ratio is reasonable. With the advantages of the 16-tower LAT, such as the smaller gap, larger solid angle covered by the ACD array, the central towers protected from albedo particles, more detailed use of the additional information, etc., the background will be reduced still further.

The 10^5 events in the balloon float data are reduced to 600 photon candidates by the filters. Based on individual examination, most of the 600 events appear to be gamma-ray events.

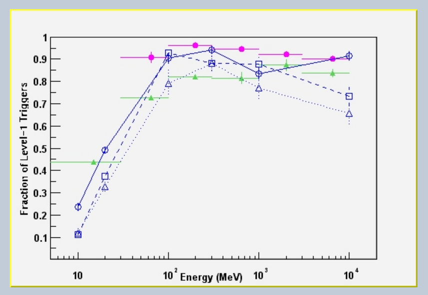


Cumulative Filtering. The fraction of observation and simulation events remaining after successive application of the filters described above. The number of Level-1 triggering events is normalized to unity. Blue line: gamma-ray simulation (300 MeV, 10 GeV, 20 MeV. Zenith angle = 30°), red line: observation data (balloon float), green line: electron simulation (primary + secondary + albedo), and magenta line: proton simulation (primary + secondary + albedo).

FILTER: TRACK-QUALITY

If (track-quality parameter < 10) then cut

The track-quality parameter is a function of the reduced χ^2 of the reconstructed tracks, the number of hits in the tracks, the number of layers without hit in the tracks, etc. (Rochester 2002). This empirically determined parameter is considered to represent a goodness of the reconstruction. Electrons/positrons may undergo Bremsstrahlung, increasing the amount of scatter, and leading to higher χ^2 and thus smaller track-quality parameter. Since high-energy gamma-rays tend to show larger track-quality parameter, an energy dependance should be introduced to this filter.



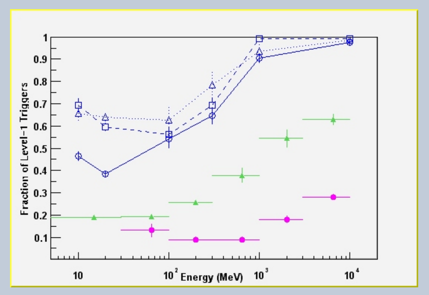
An event cut by this filter (flight data).

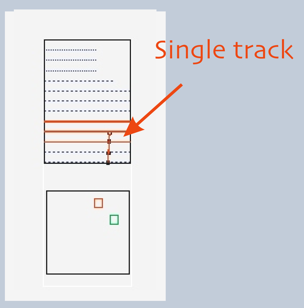
FILTER: Λ (Lambda)

If (E in CAL < 500 MeV) AND NOT (Λ in both X-Z and Y-Z views) then cut

This filter cuts events without the Λ-shape topology of pair-produced electrons. A Λ must be recognized in both of X-Z view and Y-Z view. Charged particles which make a single track, or photons whose Λ topology is somehow not properly reconstructed, are cut. To save high-energy photons which make a very narrow Λ, this filter is applied only to events below 500 MeV.

This cut is more severe than that used in the (manual) editing of EGRET events, where gamma-ray events were allowed to have only a single track in one of the two views. However, the thick-Pb layers in GLAST (which were not present in EGRET) produce a vanishingly small probability that the pair will not either separate or initiate a shower.





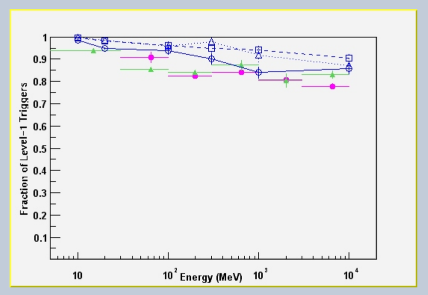
An event cut by this filter (flight data). Only one track is recognizable in this view. More tracks may be found in the other view.

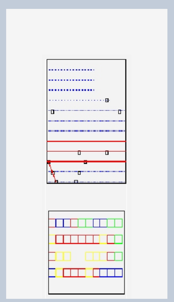
FILTER: TRACK-ABOVE-VERTEX

If (any tracks above vertex) OR (number of hits above vertex > 2) then cut

This filter cuts an event with a suspicious pattern in the tracker. Experience with data from SAS-2 and EGRET has shown that real gamma-ray events rarely show recognizable tracks above the pair-conversion point. Events with incorrect reconstruction and photons converted in the uninstrumented region of this tracker may also be cut.

In the balloon flight data, there are events cut by this filter because the pair-production event appeared to occur on level higher in on view than in the other. This can happen if the pair-production occurs in the lower layer of a tracker X-Y plane; such events can and will be accepted. Other events cut by this filtered were reconstructed incorrectly because of the uninstrumented portion of the tracker.

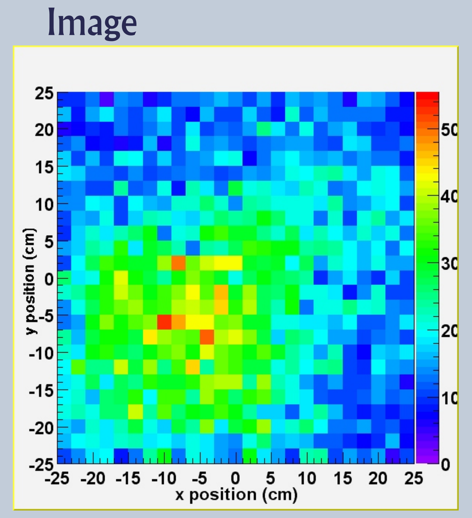




An event cut by this filter (flight data)

SELECTED PHOTON CANDIDATES

Image

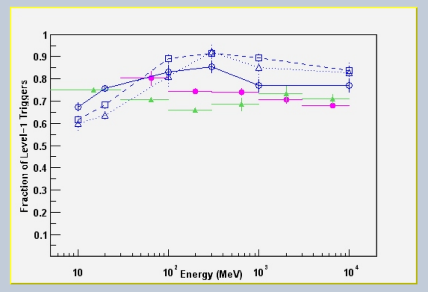


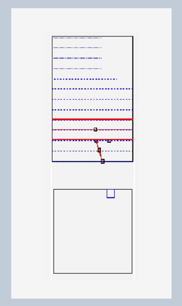
Gamma-ray candidate events projected onto the tracker's top plane. The geometrical area of the tracker is 32 cm x 32 cm. The uninstrumented portions of the tracker prevent proper reconstruction of gamma-ray events whose pair production occurs in those regions, leading to the lower population in the upper and right edges of the figure. For better statistics, events recorded during the balloon ascent are also included.

FILTER: HIT-NEAR-VERTEX

If (any hits near above vertex) then cut

This filter also cuts events with a suspicious tracker hit pattern. There should be no higher density of noise hits around the pair-production location than in other parts of the tracker, so events with excess hits around their vertex are suspicious. Events with incorrect reconstruction, as well as photons pair-converted in the uninstrumented region of the tracker, may be cut also.





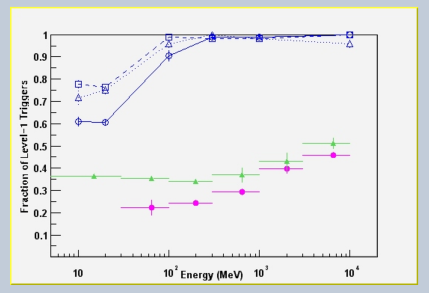
An event cut by this filter (flight data).

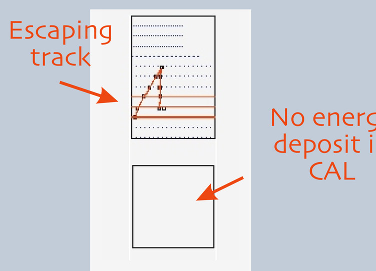
FILTER: ESCAPE-TRACK

If (E in CAL < 1 MeV) AND (any tracks escape) then cut

This filter cuts an event with no information about the energy of the (putative) gamma-ray. If the event is produced by a gamma ray, and there is no energy deposit in the calorimeter, then either the pair electrons can not penetrate the material above the calorimeter, or the electrons miss the calorimeter. In the former case, the energy of the electrons can be limited, so they are kept. We cut the events in the latter category, because there is not definitive information about their energies.

In the future, this filter will be amended to accept events with escaping tracks that are long enough to yield an energy estimate (or limit) via a multiple Coulomb scattering measurement.





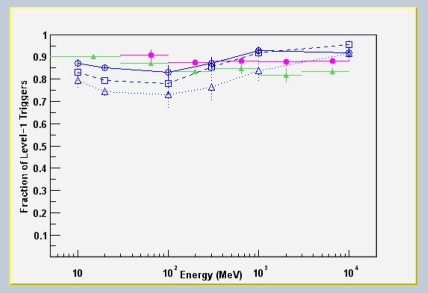
An event cut by this filter (flight data). One of the electrons misses the calorimeter and there is no energy deposit in the calorimeter.

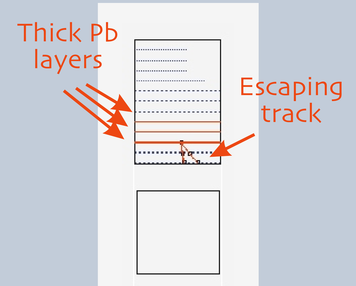
FILTER: THICK-Pb-LAYER

If (converted in a thick-Pb layer) AND (any tracks escape) then cut

The 3rd, 4th, and 5th tracker layers from the bottom have a thicker Pb foil than other layers above. This filter cuts background events due to protons or electrons which enter the calorimeter from the side and produce upward-moving particles which stop in the thick-Pb layers. It also cuts gamma-ray events which pair-convert in those layers and whose direction or energy is not known because one or both of the pair electrons miss the calorimeter. This filter is another which rejects possible gamma-ray events which are essentially useless because of unknown or poorly known direction or energy.

Unlike the ESCAPE-TRACK filter, this one cannot be amended to utilize multiple Coulomb scattering because no downward-moving track starting in the thick-Pb layers can be long enough to make that feasible.





A flight event cut by this filter - If this is a gamma-ray event, one of the electrons misses the calorimeter, and there is no energy in the calorimeter. It could also be a single heavily scattered particle, either albedo or exiting the calorimeter.

SUMMARY

Software filters for the GLAST balloon prototype to cut background events are developed. Some additional approaches to filtering for the full GLAST data are suggested.

The float data are screened with the filters and the number of the remaining photon candidates is roughly comparable to that of expected photons.

The filters are examined by applying to detailed simulation data of cosmic rays and photons. The simulations show that the remaining background events are reduced by 3 orders of magnitude.

The prototype's ability to reject background events is performed.

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